



## **Fatigue Life of Haynes 188 Superalloy in Direct Connect Combustor Durability Rig**

**Tim Gabb<sup>1</sup>, John Gayda<sup>1</sup>, Henry Webster<sup>2</sup>, Greg Ribeiro<sup>2</sup>**

**1. NASA Glenn Research Center**

**2. ATK GASL**

The Direct Connect Combustor Durability Rig (DCR) will provide NASA a flexible and efficient test bed to demonstrate the durability of actively cooled scramjet engine structure, static and dynamic sealing technologies, and thermal management techniques. The DCR shall be hydrogen fueled and cooled, and test hydrogen cooled structural panels at Mach 5 and 7. Actively cooled Haynes 188 superalloy DCR structural panels exposed to the combustion environment shall have electrodischarge machined (EDM) internal cooling holes with flowing liquid hydrogen. Hydrogen combustion could therefore produce severe thermal conditions that could challenge low cycle fatigue durability of this material. The objective of this study was to assess low cycle fatigue capability of Haynes 188 for DCR application. Tests were performed at 25 and 650°C, in hydrogen and helium environments, using specimens with low stress ground (LSG) and electro-discharge machined (EDM) surface finish. Initial fatigue tests in helium and hydrogen indicate the low cycle fatigue life capability of Haynes 188 in hydrogen appears quite satisfactory for the DCR application. Fatigue capability did not decrease with increasing test temperature. Fatigue capability also did not decrease with EDM surface finish. Failure evaluations indicate retention of ductility in all conditions. Additional tests are planned to reconfirm these positive trends.



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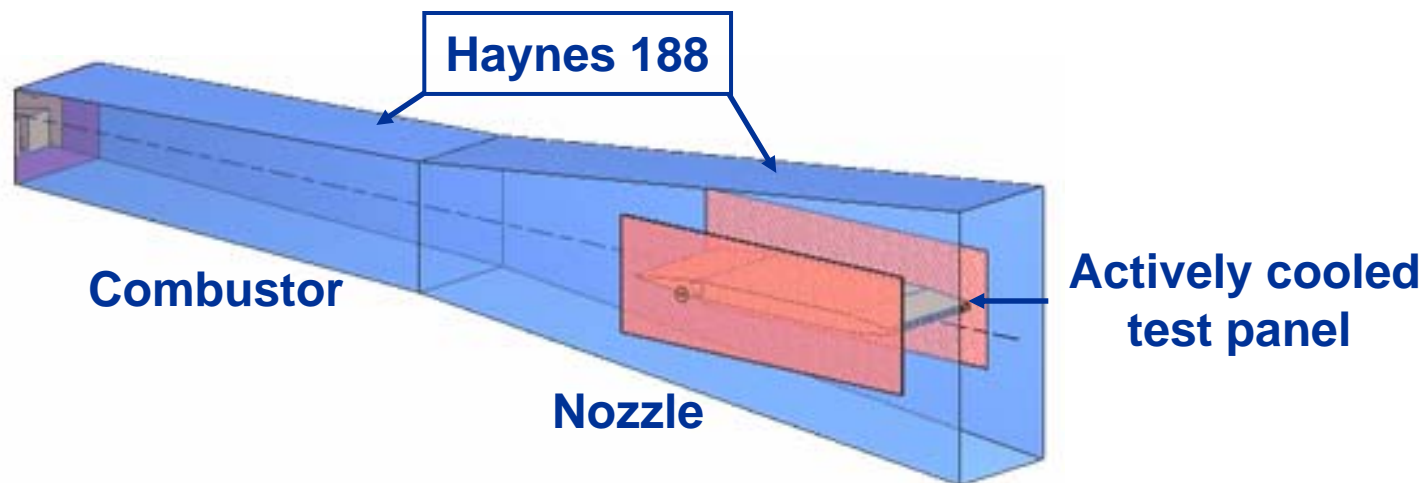
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**Fundamental Aeronautics 2007 Annual Meeting  
Hypersonics Materials and Structures  
November 1, 2007**



- The Direct Connect Combustor Durability Rig (DCR) provides a flexible and efficient test bed to demonstrate the durability of actively cooled scramjet engine structure, static and dynamic sealing technologies, and thermal management techniques.
  - DCR shall be hydrogen fueled and cooled
  - Flight-like structural test panels shall be hydrogen cooled
  - Tests planned for Mach 5 and 7 at NASA Langley Research Center





- **Statement of Problem:** Actively cooled Haynes 188 superalloy DCR panels shall encounter severe conditions that could challenge low cycle fatigue durability

#### **Haynes 188 Panel Cross-section**

- **Temperatures up to 650°C**
- **High thermal gradients**
- **Hydrogen/air high pressure environments**
- **Surface finish variations**



**Electro-discharge machined (EDM)  
hydrogen cooling passages**

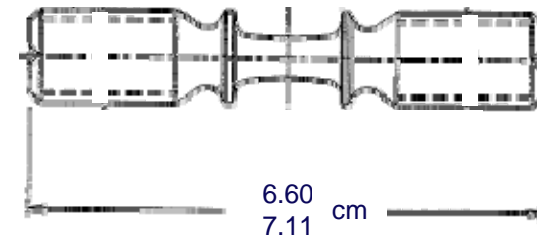
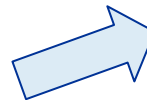
- **Objective:** Assess low cycle fatigue capability of Haynes 188 for DCR application
  - 25 and 650°C
  - Hydrogen and helium environments
  - Low stress ground (LSG) and electro-discharge machined (EDM) finish

- Progress:

- Specimens machined from dropoffs of actual Haynes 188 DCR panels
- EDM finish of cooling holes simulated on specimen surfaces
- Initial fatigue tests in helium and hydrogen completed
- Failure initiation modes compared



DCR Panel Remnants



Fatigue Test Specimens



Trial EDM Cooling Holes

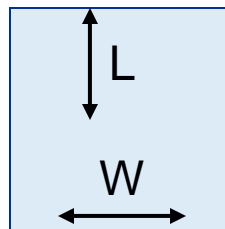
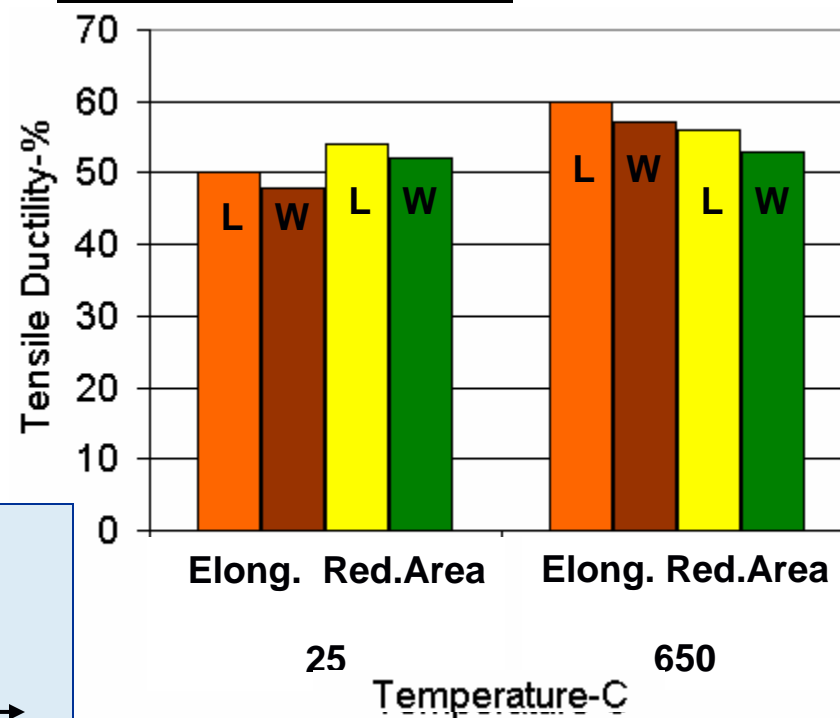
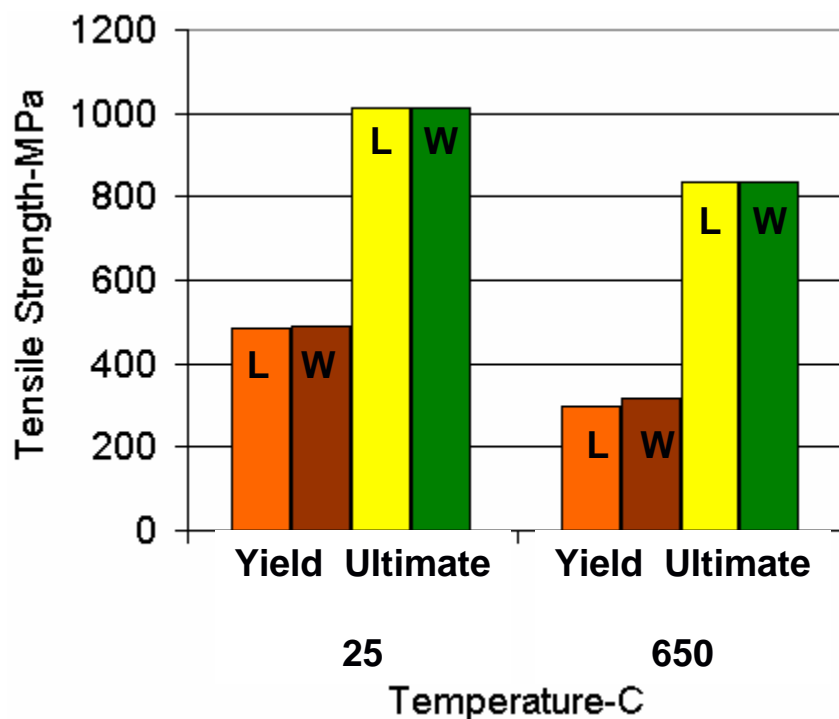
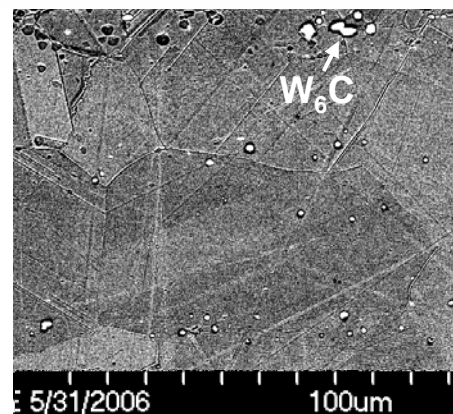
# • Haynes 188

Element	B	C	Cr	Fe	La	Mn	Ni	Si	W	Co
Weight %	0.015*	0.10	22.0	3.0*	0.03	1.25*	22.0	0.35	14.0	39 (bal.)

\* Maximum

## Haynes 188 Panel Sections

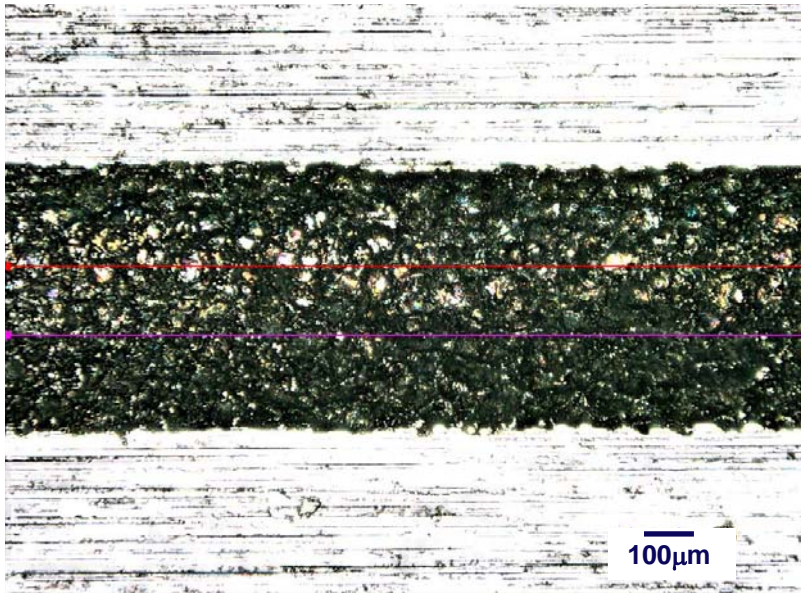
- Microstructure is  $\gamma$  FCC matrix, with scattered  $W_6C$  carbides
- Mean grain size is about 40  $\mu m$
- Tensile properties are not L-W directional, show considerable ductility for tests in air



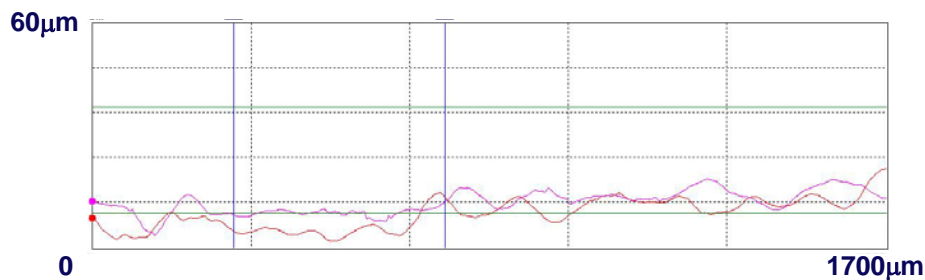
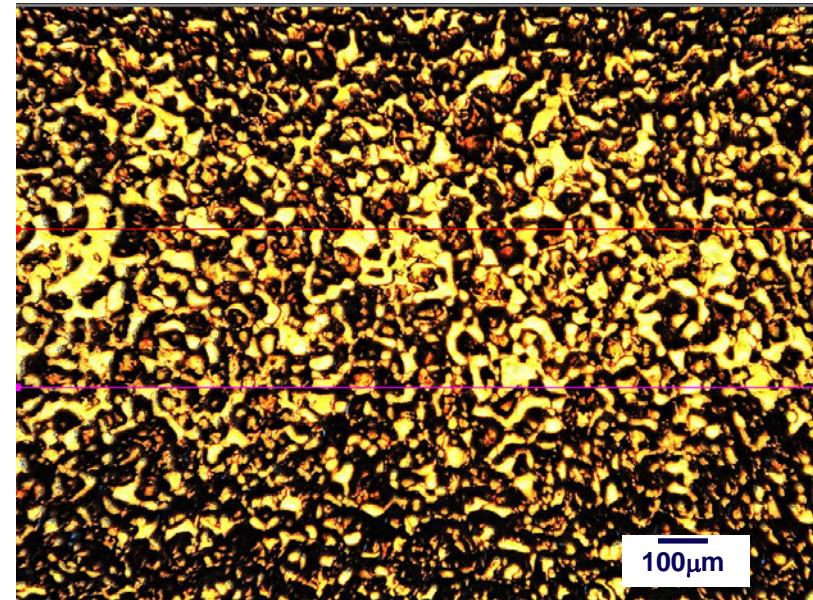


- EDM Cooling Hole Roughness Was Reproduced on the Surfaces of Selected Specimens

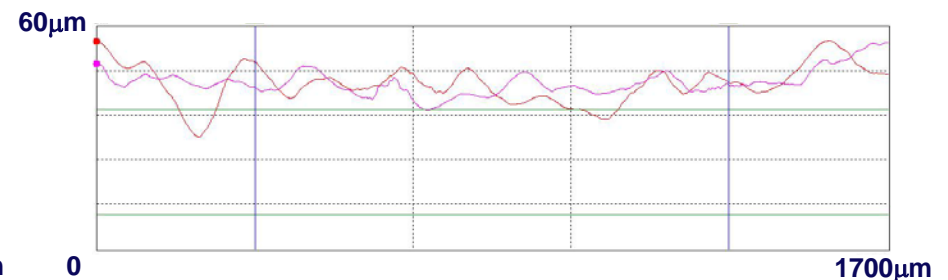
**Trial EDM Cooling Hole**



**EDM Specimen Surface**



**Hole Roughness Profile**

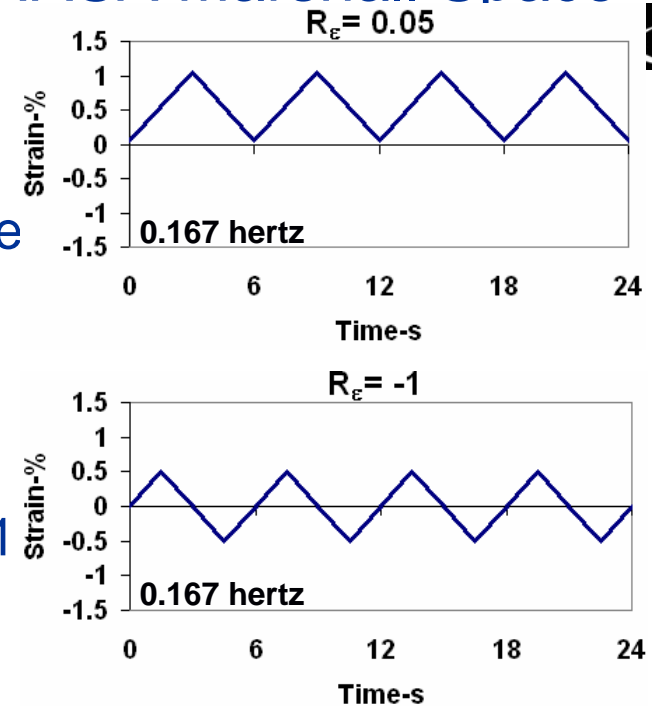


**Specimen Roughness Profile**



- **Fatigue Testing:** Performed at the NASA Marshall Space Flight Center, hydrogen test facility

- 25 and 650°C, hydrogen and helium gas environments at 34.5 MPa pressure
- Low stress ground (LSG) and EDM finish specimens
- Constant total strain range ( $\Delta\epsilon_t$ ) tests, min./max. strain ratios ( $R_\epsilon$ )=0.05 and  $-1$

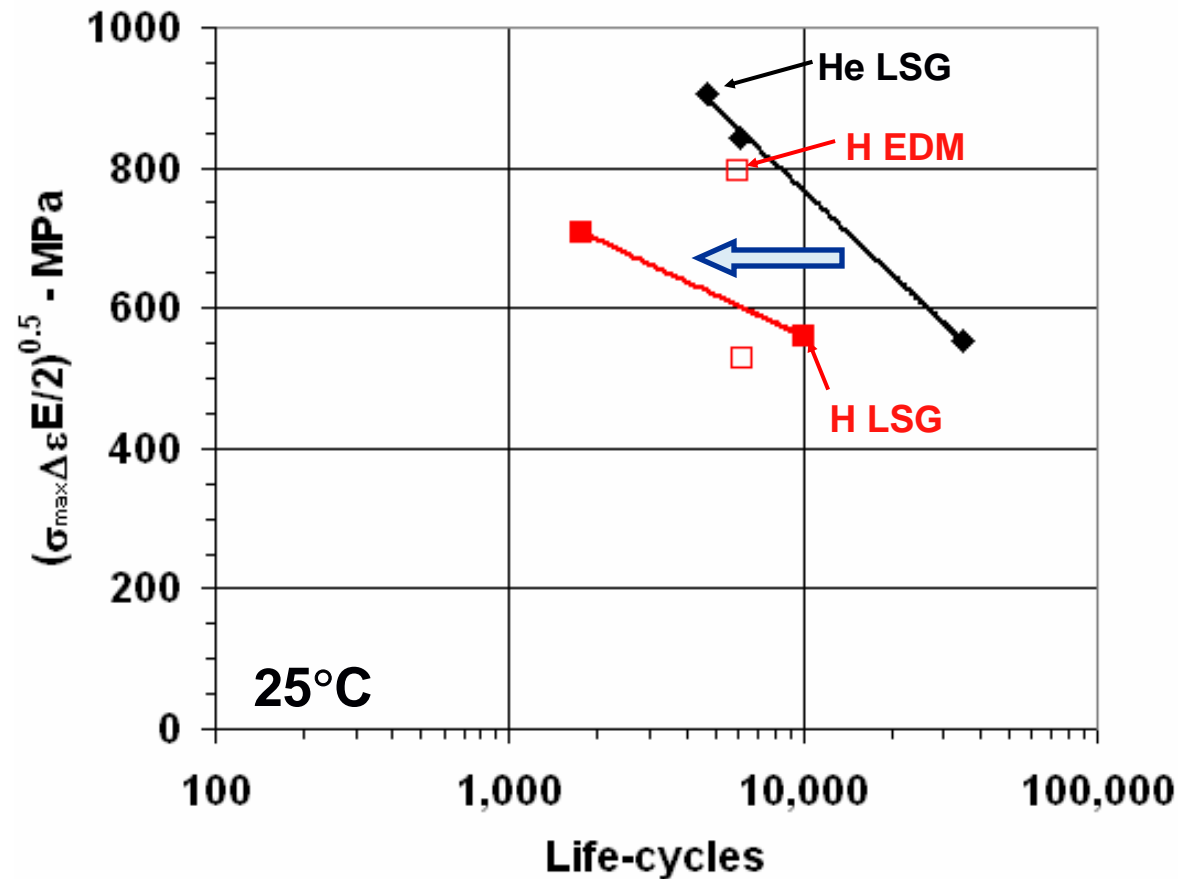


- Lives compared using the Smith-Watson-Topper stress parameter,  $SWT = (\sigma_{max} \Delta\epsilon_t E/2)^{0.5}$
- Accounts for variations in:
  - Total strain range  $\Delta\epsilon_t$
  - Maximum stress  $\sigma_{max}$
  - Elastic modulus  $E$
- NASA GRC has successfully used this fatigue parameter in past work (1) on Haynes 188





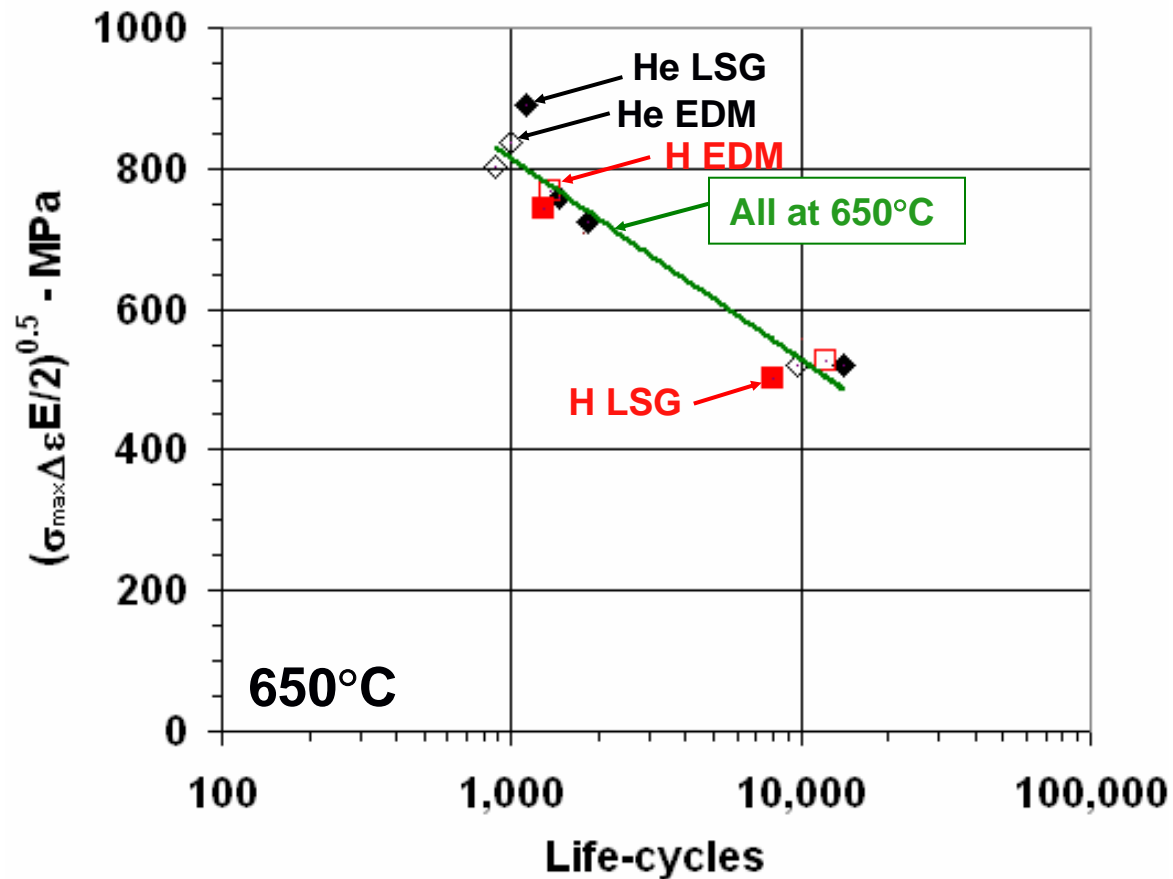
## Initial Fatigue Tests Indicate Hydrogen Reduces Fatigue Life At Room Temperature



Effect of EDM finish on fatigue life at 25°C not yet clear, potentially modest



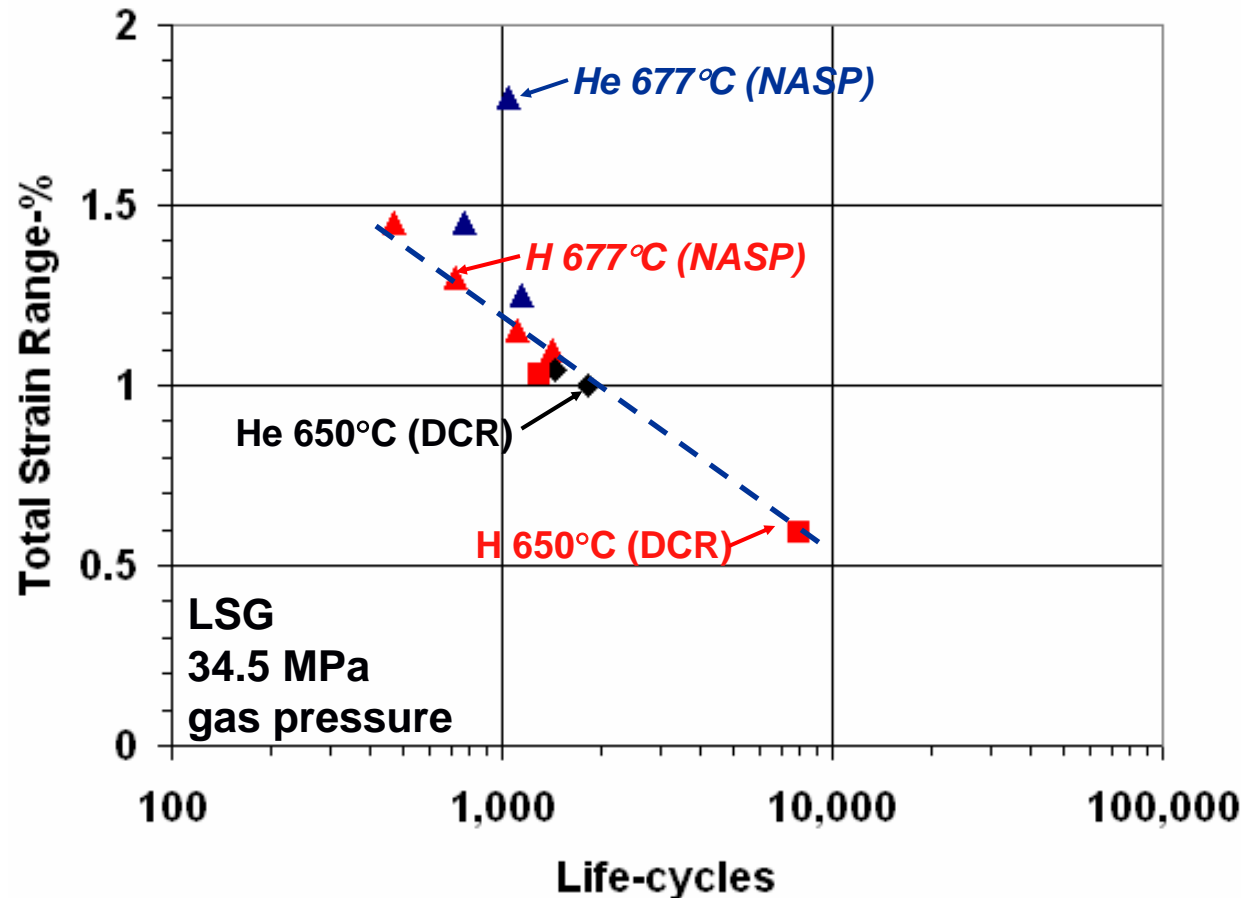
## Current Results Indicate Hydrogen Does Not Reduce Fatigue Life At 650°C



Effects of EDM finish do not appear substantial at 650°C



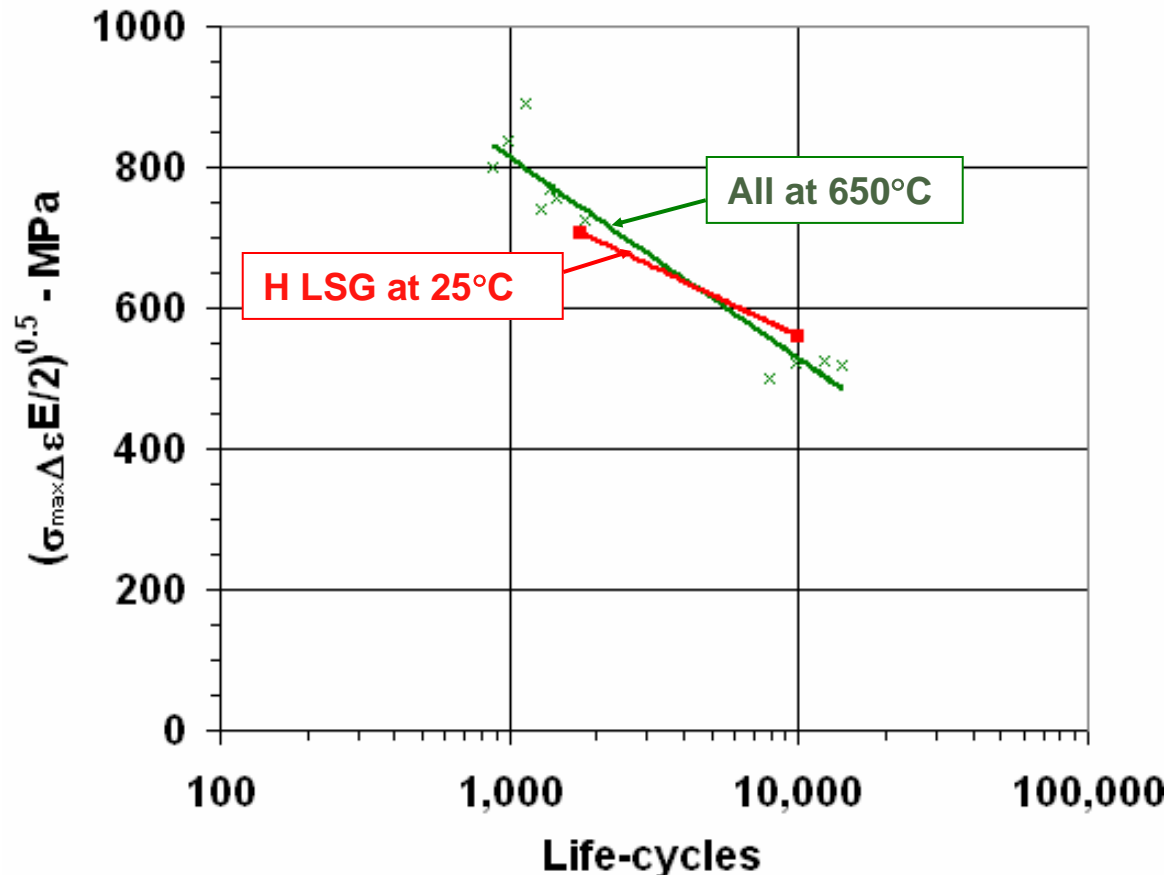
## These Promising Fatigue Results are Consistent With Early National Aerospace Plane (NASP) Tests of Haynes 188



Haynes 188 is showing sustained fatigue life in gaseous hydrogen near 650°C



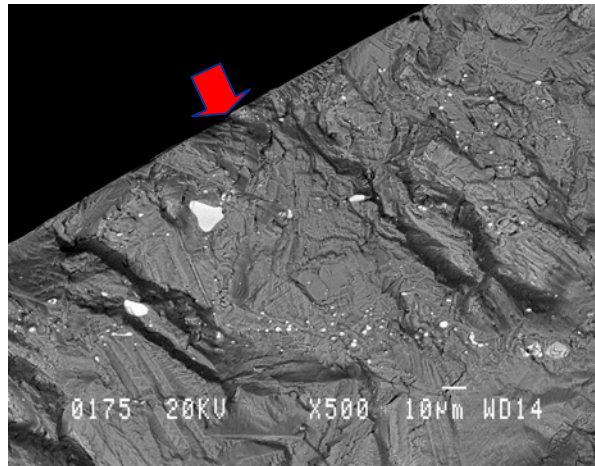
## Current Indications Are That Fatigue Life Capability in Hydrogen is Not Decreasing With Temperature or Surface Finish



Additional tests are necessary to confirm these positive trends

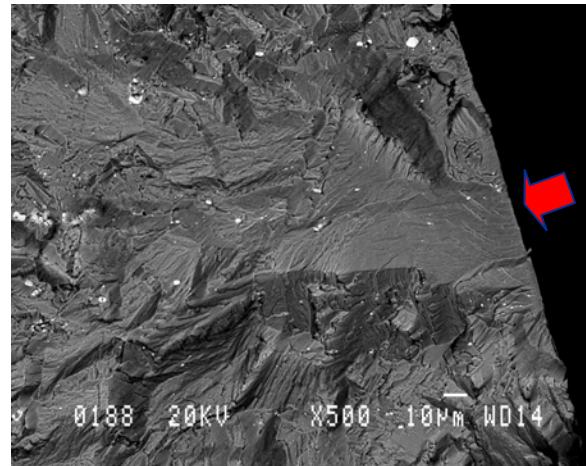
## Fatigue Failure Initiation Sites Varied At Room Temperature

**LSG / 1% Strain / He**



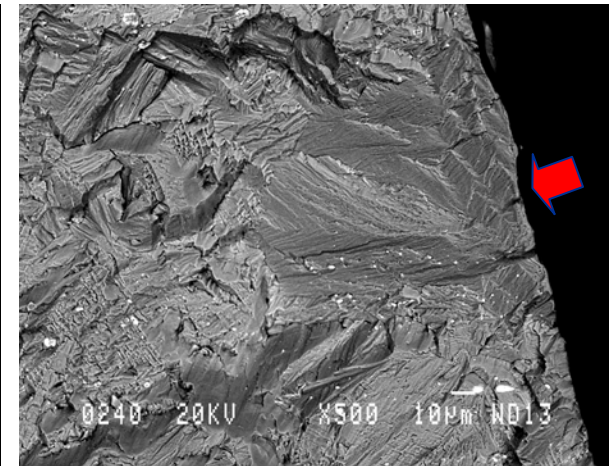
**Normal to Load Axis**

**LSG / 1% Strain / H**



**Crystallographic**

**EDM / 1% Strain / H**



**Crystallographic**

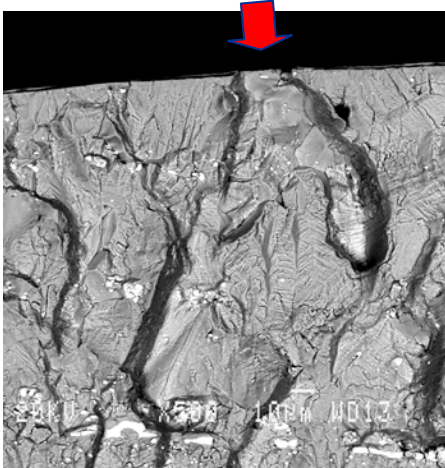
- Subsequent crack growth was transgranular, did not appear brittle

**Crystallographic grain failures initiated cracks in hydrogen**

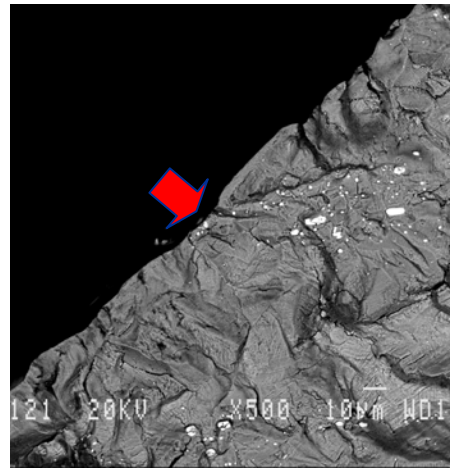


## Fatigue Failure Initiation Sites Varied At 650°C

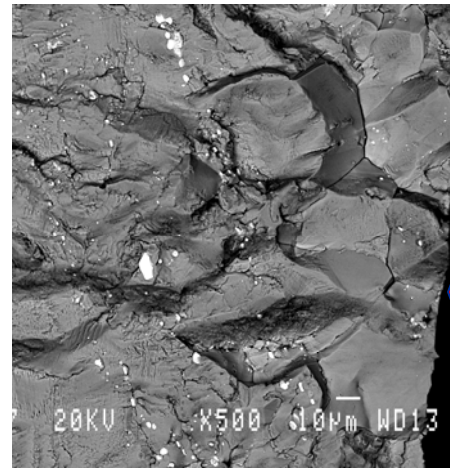
LSG / 1% Strain / He



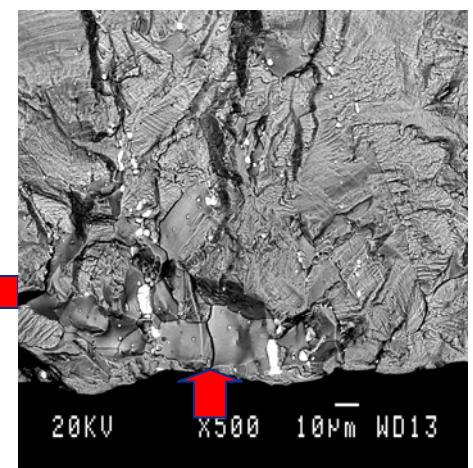
EDM / 1% Strain / He



LSG / 1% Strain / H



EDM / 1% Strain / H



➡ **More Grain  
Boundary  
Cracking** ➡

- Subsequent crack growth was transgranular, did not appear brittle

Proportion of initial grain boundary cracking increased in hydrogen



- Summary: Low cycle fatigue capability of Haynes 188 being assessed for DCR application, with good progress
  - 25 and 650°C
  - Hydrogen and helium environments
  - Low stress ground (LSG) and electro-discharge machined (EDM) finish
- Conclusions: Low cycle fatigue life capability of Haynes 188 in hydrogen looks quite satisfactory for DCR application
  - Capability not decreasing with temperature
  - Capability not decreasing with EDM surface finish
  - Failures indicate retention of ductility



- Future Work: More fatigue tests are planned
  - Run additional tests at intermediate strains
  - Perform multiple tests at strains of two selected life-limiting locations of the DCR
    - Drilled bolt hole in combustor sidewall, in air
    - EDM cooling hole, in hydrogen
  - Conduct fractography on these failed specimens
  - Generate life lines and finalize life estimates
  - Use specimen test data to correlate analytical models and refine overall structural life analysis
  - Finalize inspection intervals and procedures to monitor critical areas